ecoinvent: Materials and Agriculture

Modelling Representative Life Cycle Inventories for Swiss Arable Crops

Thomas Nemecek[1*] and Stefan Erzinger[2]

[1] Agroscope FAL Reckenholz, Swiss Federal Research Station for Agroecology and Agriculture, CH-8046 Zurich
[2] Agroscope FAT Taenikon, Swiss Federal Research Station for Agricultural Economics and Engineering, CH-8356 Ettenhausen

* **Corresponding author** (thomas.nemecek@fal.admin.ch)

DOI: http://dx.doi.org/10.1065/lca2004.09.181.8

Abstract

Goal, Scope and Background. Life cycle inventories (LCIs) of agricultural products, infrastructure, inputs and processes are required to optimise food supply chains. In the past, the use of LCA was hindered by the limited availability of databases with LCIs for such agricultural inputs, processes and products in combination with LCIs of other major economic sectors. The ecoinvent database covers this need for the Swiss, and to an extent, the European context. A suitable approach had to be outlined for defining representative datasets for products from arable crops, since there was no comprehensive survey of agricultural production.

Methods. No single data source was available for defining representative datasets for arable crops. It was therefore decided to define model crops on the basis of a variety of sources in collaboration with experts on the crops in question. The datasets were validated by experts and by comparison with literature. Field emissions were calculated using a set of models taking into account situation-specific parameters. Data defined by this procedure are more generally usable, but their definition is also more laborious.

Results and Discussion. Selected results (inventories and impact assessment) are presented for infrastructure (buildings, machinery), work processes, fertilisers, pesticides, seed and arable crop products. Infrastructure has a higher share of environmental impacts than in typical industrial processes, often due to low utilisation rates. Energy use is dominated by mechanisation, the use of mineral fertilisers (particularly nitrogen) and grain drying. Eutrophication is caused mainly by nitrogen compounds. In general, field emissions are of decisive importance for many environmental impacts.

Conclusion and Outlook. The ecoinvent database provides representative agricultural data for the Swiss, and to an extent, the European context. It also provides the meta-information necessary for deciding whether a dataset is suitable for the purpose of a particular LCA study. To further improve the representativeness of the datasets, an environmental farm monitoring network is required.

Keywords: Agriculture; arable crops; database; data modelling; ecoinvent; life cycle inventories; Switzerland

Introduction

Consumers, agencies, farmers and decision makers from the agri-food sector have become increasingly aware of the environmental impacts of agricultural production. While its share of energy consumption is relatively modest, agriculture has a high importance for certain environmental impacts such as land use or eutrophication. Life cycle assessment (LCA) has proved to be a powerful tool for the analysis of production processes in the agri-food sector (e.g. Anderson 2000, FAL 2002), but its use is hindered by the lack of representative life cycle inventory (LCI) data on agricultural products, since most data were elaborated in case studies only (Pfefferli & Gaillard 2000).

In the past, LCI databases contained no data on agriculture (e.g. Frischknecht et al. 1996), or focused on inputs into agriculture (e.g. Gaillard et al. 1997). Data collections on agricultural products were mostly limited to energy (e.g. Carlssson-Kanyama et al. 2000, Théobald 2002). Over the last few years, a large number of datasets on agriculture has been amassed for Denmark (Dalgaard et al. 2001 & 2003) and for the Netherlands (IVAM 2004).

To fill the data gaps for Switzerland, the agricultural sector was included in the ecoinvent project (Nemecek et al. 2004). The aim was two-fold:

- to provide basic data on agricultural infrastructure and inputs allowing the calculation of a variety of agricultural products, and
- to provide representative data on selected agricultural products (mainly for arable crops in the current version).

The strength of the ecoinvent database in this respect is that agricultural data are combined with data from other important economic sectors. This allows the use of the database for LCA studies of the whole food chain. General information on the ecoinvent database, its usage and methodological background is given by Frischknecht et al. (2004).

1 Goal and Scope

The goal of the life cycle inventories for arable crop products is to provide representative data valid for a given farming system (integrated, organic) in Switzerland that can be used in a variety of LCA studies.

The arable crop production systems described in the ecoinvent database are limited to the farm gate. They include infrastructure, field-work processes, inputs and some product-treatment processes that can take place on the farm (**Fig. 1**). The production and processing of the inputs and infrastructure is included from the extraction of the resources to the transport to the farm. Straw is treated as a co-product of cereals, since it is harvested in most cases. The other crops do not deliver any co-products according to current practice. Mineral fertilisers

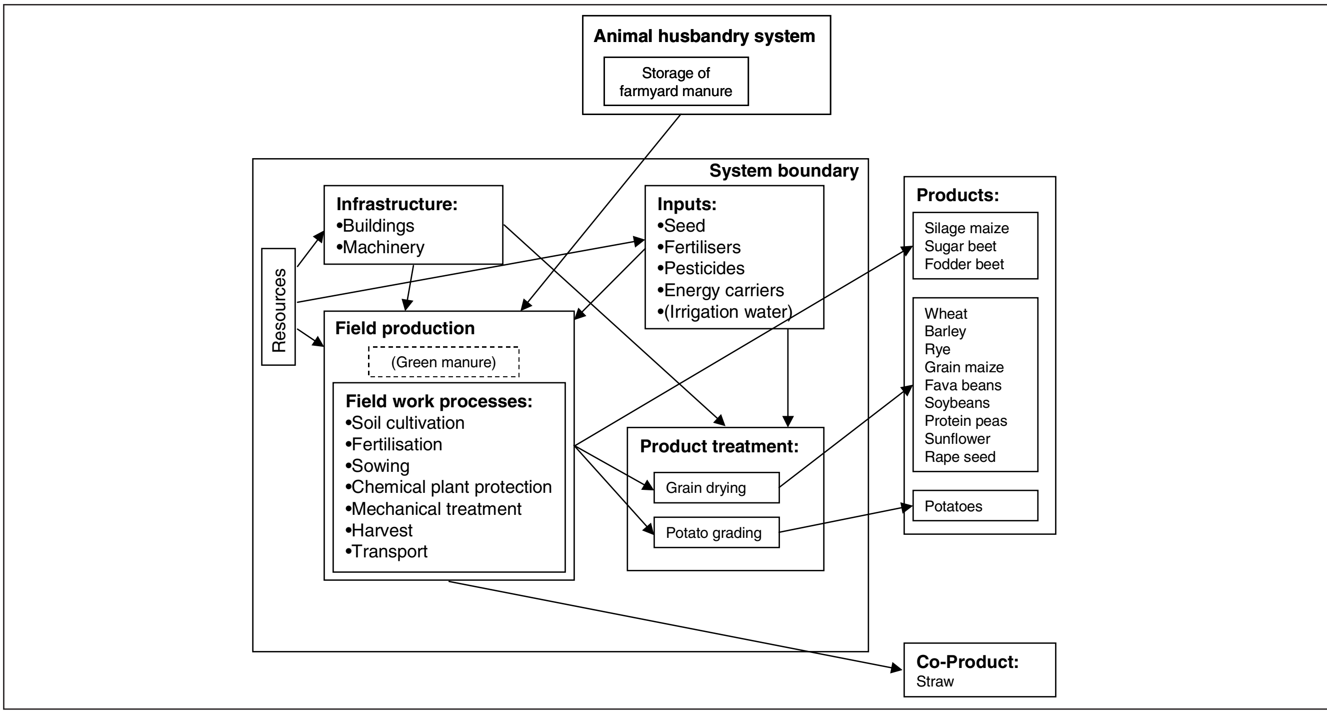

Fig. 1: System boundaries of an arable crop production system in ecoinvent. Inputs and processes in parentheses are only included in some inventories

are used in combination with farmyard manure, since most farms in Switzerland with arable crops are mixed farms. Mineral fertilisers are not allowed in organic farming systems, so farmyard manure alone is applied in this case. The arable crop production systems (see Fig. 1) comprise emissions and processes related to manure spreading, but not those related to the delivery of animal wastes and manure storage, which are fully attributed to the animal products.

2 Selecting Representative Life Cycle Inventory Data

Agricultural production differs in some important respects from industrial production processes in terms of LCI data collection:

- **Small-scale structures:** The large number of small farms makes data recording and collection very tedious. Depending on the variability of given production data, up to several hundred farms should be sampled to obtain statistically supported figures (Pfefferli & Gaillard 2000, Pfefferli et al. 2001).
- **High variability:** Due to a large number of influencing factors (climate, soil, farm size and type, etc.) the production situations and emissions are highly variable. These factors may have an influence on the LCIs and should be taken into consideration.
- **Processes are difficult to control:** Processes are largely dependent on natural systems.
- **Emissions are difficult to measure:** The emission processes are often very complex and not well understood (e.g. nitrous oxide volatilisation). In comparison with industrial processes mainly taking place in closed systems, the measurement of agricultural field emissions is difficult, if not impossible, in real situations, because most measurement techniques modify the system being studied.

Approaches which differ to an extent are therefore required to define representative datasets for agricultural production, which are described below.

2.1 Production data

To cover the data requirements for LCI, different data sources can be used to obtain representative production data:

- **Systematic statistics** on the sector level (published e.g. by the Swiss Federal Statistical Office or the Swiss Farmers' Union) are in general too aggregated and provide figures for certain aspects only. They are, however, very useful for validation purposes (Halberg et al. 2000).
- **Farm accountancy data networks** (FADNs, run by Agroscope FAT Taenikon in Switzerland) can be considered representative, but focus mainly on financial flows and lack many technical data needed for LCA (Pfefferli & Gaillard 2000, Pfefferli et al. 2001).
- **Pilot farm networks** (e.g. BLW et al. 1998, Zimmermann 2003) in general cover quite comprehensive data for the selected farms, but the sample is usually too small to be representative of the agricultural sector as a whole.
- Various **surveys** can provide useful data for specific aspects (e.g. targeted studies on fertilisers or pesticide use, or surveys of suppliers and resellers).
- **Data from agricultural extension services** usually are close to current practices, but the quality and suitability of the data is difficult to assess, since underlying data sources are usually not given.
- **Field experiments** can provide comprehensive datasets, but extrapolating from experimental to farm-practice conditions is difficult.

Two basic approaches to obtain LCIs in agriculture may be used:

- The **single-data-source approach**, where one main source only is used, such as e.g. one pilot farm network or an experiment which is only selectively completed for some missing data.
- The **modelling approach**: the LCIs are modelled by combining different data sources. For each type of data, the data source which best represents the influencing factors and the mechanisms of the investigated system is chosen.

The advantage of the single-data-source approach is its simplicity. It poses no problems with consistency and is less time-consuming. The main drawback is its lack of representativeness. The limitations of the data source also limit the validity of the LCIs. This approach was applied e.g. by Gaillard & Nemecek (2002) and Frick et al. (2001).

The advantage of the modelling approach is that it allows the creation of representative datasets in which the limitations of one data source can be overcome by other sources. The modelling approach is also more adaptable to different conditions and allows one to define various scenarios. This procedure, however, needs more work and many consistency checks in order to produce coherent datasets.

Our analysis showed that no single data source could cover the need for representative data. We therefore opted for the modelling approach in ecoinvent. We used the following criteria to choose the most suitable data source:

- Geographical coverage (ideally, the sample area should coincide with the study area, which is not always the case),
- Temporal coverage (use of most recent data),
- Sample size,
- Transparency (documentation),
- Degree of detail of the data (data which are too aggregated are not useful),
- Conformity with current practice.

The data have been modelled on FADN data combined with national statistics, recommendations (e.g. fertilisation), documents from extension services, pilot networks, legal regulations, targeted surveys and expert information (**Table 1**). A number of consistency checks and corrections were necessary to create coherent datasets. Plausibility checks were carried out by a panel of experts for the different crops and also by comparison with literature data. The details for the compilation of the inventories can be found in Nemecek et al. (2004).

2.2 Direct field emissions

Field emissions are highly variable and dependent on the actual situation. Estimating field emissions poses major problems in LCAs of agricultural systems. Brentrup et al. (2000) propose three methods for estimating field emissions in LCAs:

- measuring actual emission rates caused by the system under consideration,
- using values derived from literature in a case-by-case procedure, or
- estimating potential emission rates using structured estimation methods.

The first method was not feasible, since measuring field emissions under real conditions is difficult, if not impossible. Moreover, a very high number of measurements would have been required in order to obtain reliable estimates for average emissions. This was beyond the scope of the project.

Literature data can be used as rough approximations, mainly as constant emission rates. Few data, however, are available reflecting the situation under study. Furthermore, constant emission rates are often inappropriate and cannot reflect the influence of the farmer's management (e.g. nitrate leaching), which is a prerequisite for the improvement of production processes.

Like Brentrup et al. (2000), we therefore opted for the third method, namely, using models that can calculate emission rates depending on the actual situation (soil, climate, management). Such models are based on experiments and literature data (see Nemecek et al. 2004). The following models were used:

- **Ammonia** emissions were calculated according to Menzi et al. (1997). Constant release factors were applied in the case of mineral fertilisers. For slurry, liquid manure and solid manure, NH_4^+ content, the average monthly temperature and humidity, and the quantity of manure spread per hectare were taken into consideration.
- Potential **nitrate leaching** was estimated on a monthly basis by accounting for N-mineralisation in the soil and N-uptake by the vegetation (specific to each crop). If mineralisation exceeds uptake, nitrate leaching can potentially occur. In addition, a risk of nitrate leaching from fertiliser

Table 1: Summary of the data sources used to compile the arable-crop production inventories

Data category	Data source(s)
Yields for main products	FADN FAT (weighted means for 1996–99)
Straw yields and crop residues	Fertilising recommendations (Walther et al. 2001)
Moisture content Quantity of seed Use of machinery (number of passes)	Gross-margin catalogue from the extension service (LBL et al. 2000)
Sowing and harvest dates	Work budget (Näf 1996)
Quantity of fertilisers	Fertilising recommendations (Walther et al. 2001)
Types of fertilisers in integrated systems	Import statistics (years 1996–98 from Rossier 2000) for mineral fertilisers Pilot farm network (years 1994–96 from BLW et al. 1998) for farmyard manure
Types of fertilisers in organic systems	Pilot farm network (years 1994–96 from BLW et al. 1998) for farmyard manure
Pesticide applications	Pilot farm network (years 1994–96 from BLW et al. 1998)
Chemical seed dressing	Information provided by seed suppliers and experts

application during unfavourable periods was calculated, taking into account the crop, month of application and the potential rooting depth (Oberholzer & Walther 2001).

- Three paths of **P-emissions** to water were considered: run-off (as phosphate) and erosion (as phosphorus) to rivers as well as leaching to ground water (as phosphate). Land-use category, fertiliser type, quantity of P spread and characteristics and duration of soil cover (for erosion) were considered. The model used is derived from Prasuhn & Grünig (2001).
- **N_2O emissions** were estimated using an adapted IPCC method (Schmid et al. 2000). Indirect emissions from the conversion of NH_3 and NO_3^- into N_2O were considered in the inventories as well.
- **Heavy metal emissions** were assessed by a simple input-output balance, by calculating all inputs (fertilisers, seed, pesticides) and outputs (products and straw) to or from the field caused by the farmer. This can lead to negative emissions on the field level in some cases.
- **Pesticide applications** were accounted for as emissions of the active ingredients into agricultural soil.
- Calculation of the **tractor combustion emissions** is explained in chapter 3.2.

2.2 Resource use

CO_2 uptake by the vegetation was included (resource 'Carbon dioxide, in air') as well as the potential heat energy of the biomass (resource 'Energy, gross calorific value, in biomass'). The content of organic C in the soil was assumed to be constant. In ecoinvent, the biotic emissions of CO_2 ('Carbon dioxide, biogenic' in air) were clearly separated from the release of CO_2 during the combustion of fossil fuels ('Carbon dioxide, fossil' in air). This gives the database user the option of either considering biotic CO_2 flows (including CO_2 release during the use of the agricultural product) or omitting them in the impact assessment phase.

Land occupation and transformation were recorded for agricultural land as well as for non-agricultural areas (see Althaus et al. 2004 for the methodology).

3 Datasets Required for Modelling Arable Crop Production

A variety of inputs from the technosphere are needed to model arable crop production systems:

- Infrastructure: machinery, buildings,
- Work processes (including the use of energy carriers),
- Seed,
- Fertilisers,
- Pesticides.

The inventories for these inputs are described below (see Nemecek *et al.* 2004 for details). For simplicity's sake, results are given mainly for the impact assessment phase.

3.1 Infrastructure: Machinery and buildings

For arable crop production, different kinds of machines and equipment are used. As this machinery has often considerable size and a low operation time, it is important to include the infrastructure in life cycle assessments of agricultural systems.

The agricultural machinery was categorised into six classes. For each class, the typical composition was estimated (**Table 2**). This estimate is based on manufacturer's information and expert statements.

Manufacturing, maintenance, repair and disposal of the machinery were included, as well as transportation from place of manufacture in Western Europe to farms in Switzerland. Data were derived from various sources for agricultural machinery and lorries, namely Ammann (2001) and Maibach et al. (1999).

The functional unit of all six classes of machinery is one kilogram of machine during its entire lifetime. The machinery is allocated between the process considered and other uses, using information on operation time for the process and lifetime of the machinery (Gaillard et al. 1997).

Building infrastructure is more important for animal farming than for crop production, where only a machine shed (wood construction) is used (see Fig. 1).

3.2 Work processes

Work processes in arable farming are time- and fuel-consuming and are therefore important for life cycle assessment. For ecoinvent, a total of 32 work processes have been modelled (e.g. tillage, fertilisation, irrigation, harvesting and transport). The work processes include the infrastructure used (machinery and shed attributable to the process), the diesel fuel used as well as emissions to air from combustion and to soil from tyre abrasion during field work.

Fuel consumption and tractor-engine load spectra were measured on-site for various agricultural work processes by Rinaldi (2004). Data for engine emissions of HC, NO_x and CO are based on models derived from test-bed measurements on 112 tractors of different sizes, types and makes (Rinaldi 2004). Emission factors for other air emissions were completed from SAEFL (2000). For the two work processes 'ploughing' and 'harvesting, potatoes', the contribution of infrastructure

Table 2: Typical composition of the six different machinery classes investigated (% of weight)

Machinery classes	Tractor	Harvester	Trailer	Machinery, general	Machinery, tillage	Slurry tanker
Steel, unalloyed	67%	70%	70%	84%	84%	82%
Steel, alloyed	10%	10%	5%	11%	15%	10%
Other metals	8%	8%	19%	1%	1%	2%
Rubber	10%	7%	5%	3%	0%	5%
Plastics	3%	3%	0%	0%	0%	0%
Others (glass, paints, etc.)	2%	2%	1%	1%	0%	1%

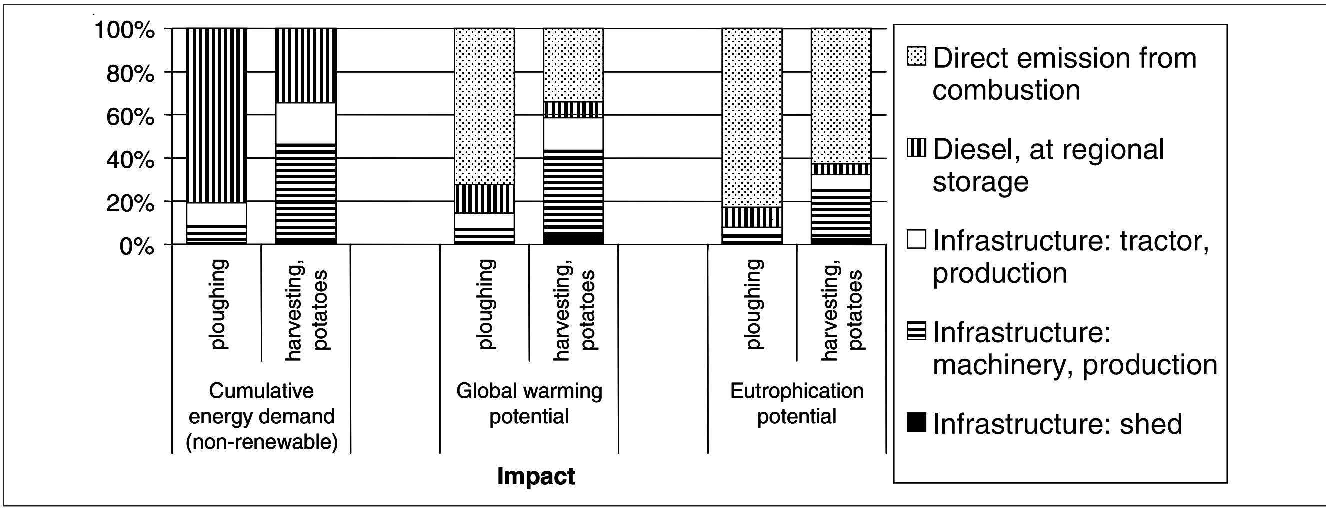

Fig. 2: Contribution of infrastructure (shed, machinery, tractor), diesel supply and combustion emissions to the total of selected impact categories for the work processes 'ploughing' and 'harvesting, potatoes'. (Cumulative energy demand (non renewable, fossil and nuclear), global warming potential for 100 years according to the IPCC method 2001 and eutrophication potential according to CML 2001, as implemented in ecoinvent.)

supply, fuel consumption and emissions from combustion to selected impact categories is given as examples in **Fig. 2**. Ploughing is a work process with a high power demand, so non-renewable energy use is dominated by diesel consumption during field work, whilst infrastructure contributes almost 20%. By contrast, harvesting potatoes with a one-row complete harvester is a time-consuming process with low power demand; consequently, the infrastructure share is substantially higher.

3.3 Seed

The delivery process for seed comprises the following phases:

1. Agricultural seed production,
2. Transport to the seed-processing centre,
3. Processing the seed (pre-cleaning, cleaning, chemical seed dressing and bag filling),
4. Seed storage,
5. Transport to regional storehouse or final user.

In ecoinvent, datasets for seed production can be found at two levels: 'at farm', including phase 1 above, and 'at regional storehouse', including steps 1–5. The data were based on a survey of seed producers and suppliers, as well as on literature.

Agricultural field production is responsible for the largest share of the impacts (e.g. acidification potential as shown in **Fig. 3**). For sugar beet, which requires long transports and intensive processing, the share of transport, processing and storage is larger than for other kinds of seed. Not only the acidification potential per kg seed is different, but also the quantity of seed required per ha (e.g. from 2 kg/ha for sugar beet to 2500 kg/ha for potato seed, see Fig. 3).

3.4 Fertilisers

Twenty-four datasets were defined for mineral, six for organic fertilisers. The datasets for mineral fertilisers always refer to the main nutrients N, P or K and have the units kg

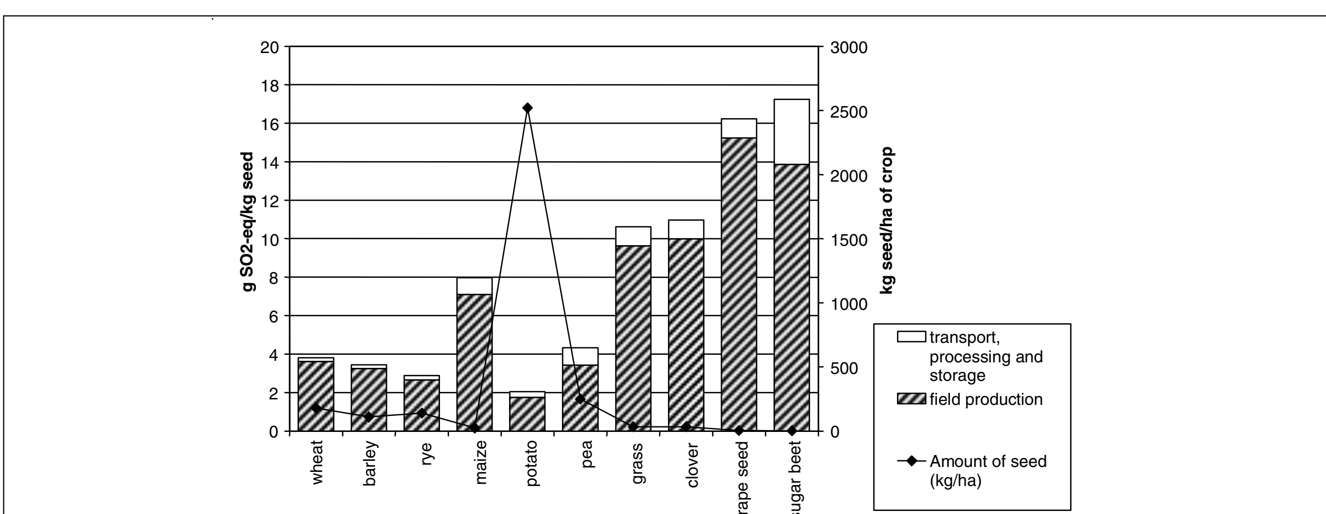

Fig. 3: Acidification potential (CML-method 2001) for field production, transport, processing and storage of seed (bars, in g SO_2-equivalents/kg seed). The line shows the amount of seed typically used per ha of crop

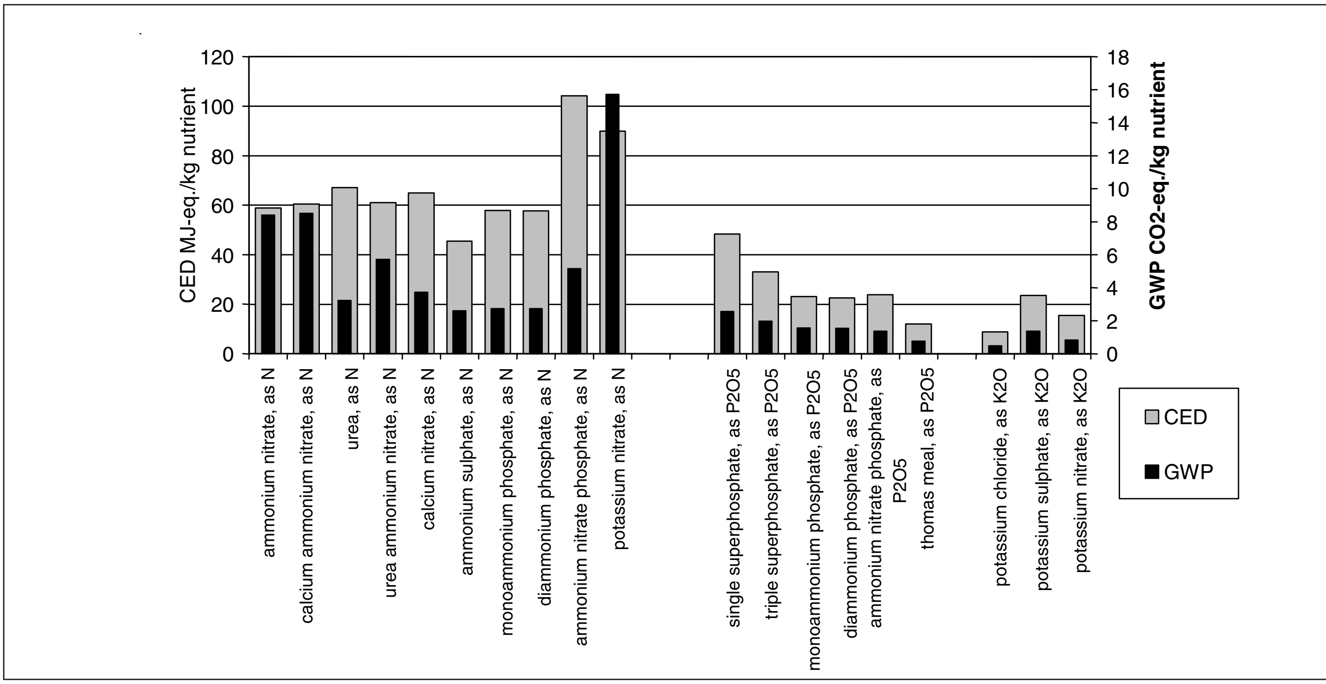

Fig. 4: Cumulative energy demand (non-renewable resources, CED) and global warming potential (GWP) for 100 years according to the IPCC method 2001 for various mineral fertilisers

N, kg P_2O_5 or kg K_2O, respectively, units used by farmers to calculate the nutrient needs of crops. This procedure also makes the comparison of the different fertilisers easier. In the case of multi-nutrient fertilisers (NP- and NK-fertilisers) an allocation was performed between the two main components (based on energy and mass, respectively).

The data were derived from literature (Davis & Haglund 1999, Patyk & Reinhardt 1997, Kongshaug 1998) and corporate environmental reports (K+S Aktiengesellschaft 2001). Data on organic fertilisers, lime and stone meal were collected in our own surveys.

Energy use and global warming potential (GWP) are highest for N fertilisers, medium for P fertilisers and lowest for K fertilisers (**Fig. 4**). NH_3 synthesis is the most energy-intensive step for N fertilisers. Nitric-acid-based fertilisers show high values for GWP, due to nitrous oxide losses during the synthesis of nitric acid. The GWP of urea is low, since 0.44 kg C/kg N is fixed during the production of urea, corresponding to 1.6 kg CO_2/kg N. However, this carbon is released to air after the application in the field, leading to a higher GWP in total.

Since there are large differences between the different types of fertilisers, both fertiliser type as well as quantity must be known for LCAs of agricultural systems.

3.5 Pesticides

Inventories were defined for active ingredients but not for commercial products, on the one hand, because of the large variety of commercial products (with different combinations of active ingredients), on the other hand, because the synthesis of the active ingredients is, in general, much more important than the formulation of the final product (Green 1987).

Nineteen inventories for classes of pesticides and 14 inventories for individual active ingredients were defined. In addition, an average dataset 'pesticide unspecified' was calculated for use in situations where no specific information is given about the active substances used, or where the inventory for a particular class of pesticides is not available.

The datasets are based on Green (1987) and derived from the energy use reported for a variety of pesticides. These inventories can be used as rough approximations in LCAs of agricultural systems, but are not suitable for other purposes such as comparison with other chemicals. Despite its age, Green (1987) is still the data source most widely used in agricultural LCAs.

The results of recent LCA studies (e.g. Nemecek et al. 2002) show the environmental impact of pesticide manufacture to be relatively small. Pesticide application in the field, however, may have a significant toxic effect.

As the CED non-renewable varies between the different active ingredients by a factor of 10, it is important to know which active ingredients are used.

4 Selected Results for Arable Crop Products

Fifty-six datasets were defined in ecoinvent for the most important arable crop products, namely wheat, barley, rye, rape seed, sunflower, grain maize and silage maize, potatoes, sugar beet and fodder beet, fava beans and soybeans, and protein peas (Nemecek et al. 2004). The datasets are valid for the Swiss lowlands, where the largest share of Swiss arable land is to be found.

Datasets for most crops were broken down according to the two farming systems in use:

- **Integrated production** (**IP**) is the most common farming system in Switzerland, used in about 85% of farms (BLW 2003). Farmers must respect a set of ecological standards in order to obtain subsidies.
- **Organic farming** is practised by 10% of Swiss farmers. The farmers must comply to more restrictive ecological standards and are certified by independent experts.

No inventories were defined for the 5% of farms practising conventional farming. For the integrated production of cereals and rape seed, two different production modes were modelled according to current Swiss practice: *intensive production* and *extensive production*. The use of fungicides, insecticides and growth regulators is forbidden in the latter.

For spring-sown crops (sunflower, maize, potatoes, beets, beans and peas), a green manure (catch crop) is included in the inventory in winter (see Fig. 1), because integrated and organic farming systems stipulate that the soil must be covered in winter. For autumn-sown as well as spring-sown crops, a period of approx. one year is covered, making different crops comparable.

Below, the database is illustrated with two examples of environmental impacts of agricultural products.

The CED of non-renewable energy resources (fossil and nuclear, **Fig. 5**) is dominated by three factors:

1. the use of machines (mechanisation),
2. mineral fertilisers,
3. grain drying.

The use of machines requires energy resources for their manufacture and maintenance, for the construction and maintenance of the housing shed and for the combustion of fuels during operation. The most relevant processes are soil cultivation and harvest. The largest energy-saving potential exists mainly for soil cultivation using minimum-tillage or no-tillage methods.

Production of the mineral fertilisers – especially N fertilisers – creates high energy demands (see Fig. 4). The contribution of mineral fertilisers is highest for cereals and oil crops, and lowest for legume crops (fava beans, soybeans and protein peas), which thanks to symbiotic nitrogen fixation do not require any N fertiliser.

The importance of grain drying depends on the moisture content at harvest and at storage. Only grains need to be dried; the contribution of drying is by far highest for grain maize (drying from 39% to 14% moisture by weight), medium for oil crops (rape seed and sunflower) and grain legumes (fava beans, soy beans and protein peas) and lowest for cereals. Harvesting in dry conditions can substantially reduce consumption of energy resources.

Pesticide production is of minor importance for the CED non-renewable. Seed has a low importance for most crops, although it has a higher share for potatoes and grain legumes (see also Fig. 3). For spring-sown crops, green manure has some importance, which largely depends on the yield.

The nutrient enrichment potential (eutrophication) according to the EDIP method is dominated by N-compounds (**Fig. 6**). Field emissions, particularly nitrate leaching, are primarily responsible for the eutrophication potential. Sunflower and soy beans show high values because of a relatively high risk of nitrate leaching in spring and autumn, and comparatively low yields.

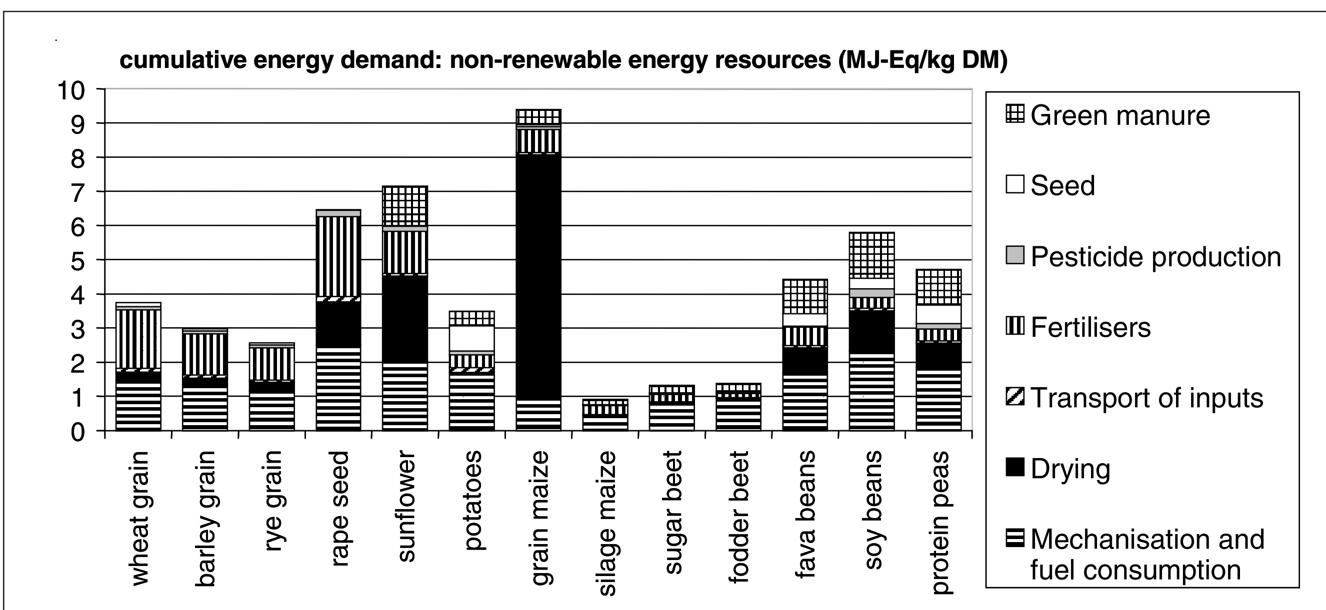

Fig. 5: Cumulative energy demand (non-renewable resources, fossil and nuclear) of selected arable crops (from integrated intensive production) related to 1 kg of dry matter (DM) produced

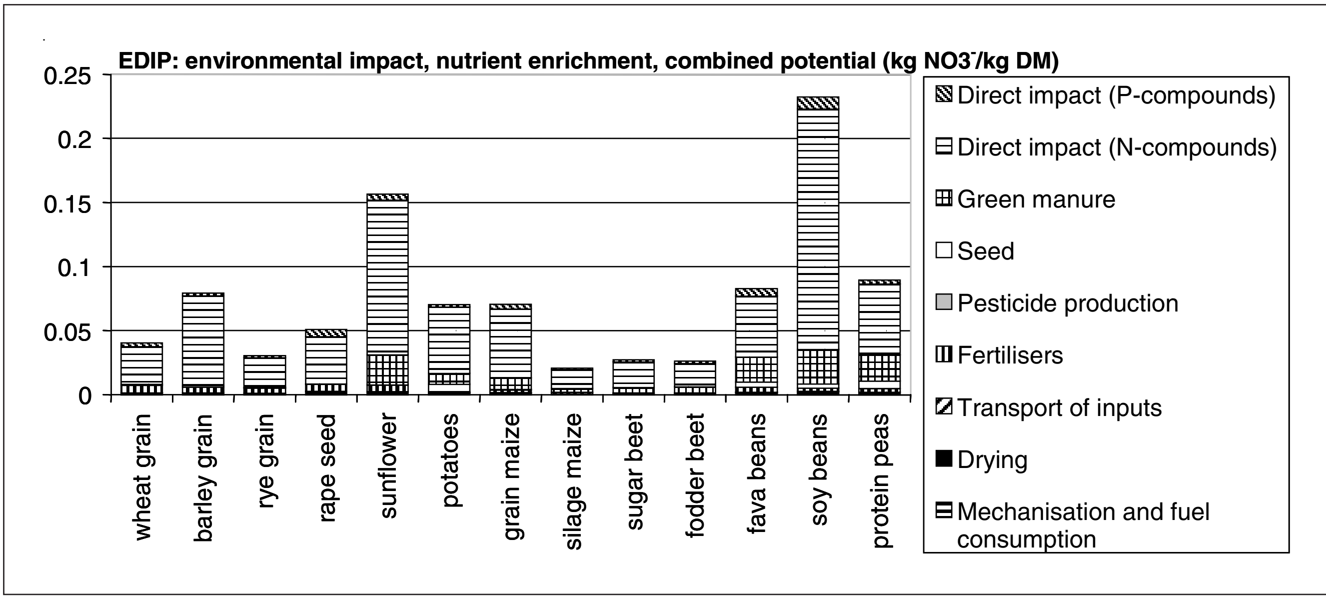

Fig. 6: Nutrient enrichment (eutrophication potential, combined potential of N- and P-compounds according to the EDIP method 1997) of selected arable crops (from integrated intensive production) related to 1 kg of dry matter (DM) produced

5 Conclusions and Outlook

The datasets are valid for average situations under given constraints. In particular field situations, there might be large deviations from these averages. When using ecoinvent datasets for LCA studies, the extent to which the data requirement of the LCA study is met must be determined. The meta-information on data quality (temporal, geographical and technological coverage, precision, completeness and representativeness), and the qualitative and quantitative descriptors of uncertainty, allow this assessment to be performed.

ecoinvent data on agriculture represent averages either at a European level (as for fertilisers and pesticides) or for typical Swiss conditions (other inputs such as buildings, machinery, work processes, seed and feed, as well as all agricultural products). An extrapolation from Swiss data to other European countries is possible only for comparable conditions. For arable crop products, this means that yield, amount of fertilisers and pesticides applied, and climate and soil are similar. The datasets on arable crops can be used in moderate-to-low-intensity production systems, since this is the typical production situation in Switzerland. Differences in environmental impacts per kg of product are usually much smaller than differences per ha of crop (see e.g. Gaillard & Nemecek 2002), because intensive production usually creates both higher emissions and higher yields. This means that extrapolations per kg of product are easier than per ha of crop. Whether an extrapolation is possible depends also on the specific data quality requirements of the study.

The datasets for arable crops are intended for analyses of whole process chains (e.g. in the food industry) and not for the evaluation of farming systems as such. This is because LCAs of products are limited to subsystems of a farm and are not suitable for comparisons between whole farming systems, such as integrated and organic systems which are defined at farm level. A difference in the spreading of farmyard manure causes major differences in environmental impacts for individual crops, which disappear wholly or in part if the whole system is considered (Nemecek et al. 2001). Furthermore, several environmental problems (e.g. nitrate leaching) can only be studied in the context of the crop rotation.

The modelling approach applied in ecoinvent has proved to be useful for the definition of the LCIs of arable crops, and has provided a set of representative LCIs for Swiss conditions. Compared to the use of a single data source, the method is more time-consuming and requires a great deal of care to produce a coherent set of data, due to possible inconsistencies and even contradictions between different data sources. By defining model crops and combining different data sources and models, the limitations of a given data source can be counterbalanced. Unless a monitoring network with large samples and detailed data recording is available, the modelling approach is recommended to provide representative data.

A complete validation of the datasets could not be performed, since production and environmental data are not comprehensively monitored. Only plausibility tests and selective validations could be carried out. In-depth validation would have required a systematic environmental survey of agricultural production. Such a farm-monitoring network is planned in the recently launched LCA-FADN project (Gaillard & Erzinger 2002, Pfefferli et al. 2001). In a network of about 300 farms, detailed production data will be recorded on a yearly basis over three years, which will provide a valuable set of production data for further improving LCI databases on agricultural products and processes.

References

Althaus HJ, Kellenberger D, Doka G, Künniger T (2004): Life Cycle Inventories of Building Materials and Methodological Aspects of Inventorying Infrastructure. Int J LCA 10 (1) ##–##

Ammann H (2001): Maschinenkosten 2002. FAT-Berichte Nr. 569. Agroscope FAT Taenikon, Ettenhausen

Andersson K (2000): LCA of food products and production systems. Int J LCA 5 (4) 239–248

BLW (2003): Agrarbericht 2003 des Bundesamtes für Landwirtschaft. BLW Berne

BLW, FAT, FiBL, LBL, SRVA (1998): Ökologische und produktionstechnische Entwicklung landwirtschaftlicher Pilotbetriebe 1991 bis 1996 – Schlussbericht der nationalen Projektgruppe Öko-Pilotbetriebe. FAT Taenikon, Ettenhausen

Brentrup F, Küsters J, Lammel J, Kuhlmann H (2000): Methods to estimate on-field emissions from crop productions as an input to LCA studies in the agricultural sector. Int J LCA 5 (6) 349–357

Carlsson-Kanyama A, Faist M (2000): Energy Use in the Food Sector: a Data Survey. Swedish Environmental Protection Agency, Stockholm

Dalgaard R, Halberg N, Kristensen IS, Larsen I (2003): An LC inventory based on representative and coherent farm types. Proceedings of the 4th International conference on life cycle assessment in the agri-food sector, 6.–8.10.03, Horsens, Denmark

Dalgaard T, Halberg N, Porter JR (2001): A Model for Fossil Energy Use in Danish Agriculture Used to Compare Organic and Conventional Farming. Agriculture Ecosystems & Environment 87 (1) 51–65

Davis J, Haglund C (1999): Life Cycle Inventory (LCI) of Fertiliser Production – Fertiliser Products Used in Sweden and Western Europe. Chalmers University of Technology, Gothenburg, SIK Report no. 654

FAL (2002) Ökobilanzen – Beitrag zu einer nachhaltigen Landwirtschaft. Schriftenreihe der FAL 38, FAL Reckenholz, Zurich

Frick C, Dubois D, Nemecek T, Gaillard G, Tschachtli R (2001): Burgrain: Vergleichende Ökobilanz dreier Anbausysteme. Agrarforschung 8 (4) 152–157

Frischknecht R, Bollens U, Bosshart S, Ciot M, Ciseri L, Doka G, Dones R, Gantner U, Hischier R, Martin A. (1996): Ökoinventare von Energiesystemen. Grundlagen für den ökologischen Vergleich von Energiesystemen und den Einbezug von Energiesystemen in Ökobilanzen für die Schweiz. 3rd edition, Gruppe Energie – Stoffe – Umwelt (ESU), Eidgenössische Technische Hochschule Zürich und Sektion Ganzheitliche Systemanalysen, Paul Scherrer Institut Villigen/Würenlingen

Frischknecht R, Jungbluth N, Althaus H-J, Doka G, Dones R, Hellweg S, Hischier R, Nemecek T, Rebitzer G, Spielmann M (2004): Survey of and Methodological Framework for the ecoinvent Database. Int J LCA 10 (1) ##–##

Gaillard G, Crettaz P, Hausheer J (1997): Umweltinventare der landwirtschaftlichen Inputs im Pflanzenbau. Schriftenreihe FAT 46. FAT Taenikon, Ettenhausen

Gaillard G, Erzinger S (2002): Using a Central Data Network of Farm Life Cycle Assessment as Basis for a National Environmental Indicator System. In: International Conference 'Agricultural Statistics in the new Millenium: the Challenge of Agri-environmental Indicators as a Tool for the Planning of Sustainable Development in Agriculture', Chania, 13–15 Nov 2002

Gaillard G, Nemecek T (2002) Ökobilanzierung des Extensoanbaus von Getreide und Raps. Agrarforschung 9 (11–12), 490–495

Green MB (1987): Energy in pesticide manufacture, distribution and use. In: Helsel ZR (ed.) Energy in Plant Nutrition and Pest Control, Energy in World Agriculture Vol. 2: 165–177

Halberg N, Kristensen IS, Dalgaard T (2000): Linking data sources and models at the levels of processes, farm types, and regions. In: Weidema BP, Meeusen MJG (eds.) Agricultural data for life cycle assessments, Vol. 1. Agricultural Economics Research Institute, The Hague, The Netherlands, 16–30

IVAM (2004): IVAM LCA Data 4 – IVAM LCA Database in SimaPro 5 format. IVAM research and consultancy on sustainability, Amsterdam. Retrieved from http://www.ivambv.uva.nl/uk/producten/product5.htm

K+S Aktiengesellschaft (2001): Umweltbericht 2001, K+S-Gruppe. Retrieved from http://www.k-plus-s.com/pdf_de/2001/umweltbericht.pdf

Kongshaug G (1998): Energy consumption and greenhouse gas emissions in fertilizer production. Hydro Agri Europe, Norway. EFMA Seminar on EU Legislation and the Legislation Process in the EU relative to Fertilizer, Prague, 19–21 Oct 1998

LBL, SRVA & FiBL (2000): Deckungsbeiträge – 2000 Edition. LBL Lindau

Maibach M, Peter D, Seiler B (1999): Ökoinventar Transporte. Grundlagen für den ökologischen Vergleich von Transportsystemen und für den Einbezug von Transportsystemen in Ökobilanzen, 2nd edition. Infras, Zurich

Menzi H, Frick R, Kaufmann R (1997): Ammoniak-Emissionen in der Schweiz: Ausmass und technische Beurteilung des Reduktionspotentials. Schriftenreihe der FAL 26, FAL Reckenholz, Zurich

Näf E (1996): Arbeitsvoranschlag – Datenkatalog für den Arbeitszeitbedarf der landwirtschaftlichen Arbeiten. FAT Taenikon, Ettenhausen

Nemecek T, Frick D, Dubois D, Gaillard G (2001): Comparing farming systems at crop rotation level by LCA. International Conference on LCA in Foods, 26–27 Apr 2001, Gothenburg. SIK-Document 143, 65–69

Nemecek T, Heil A, Huguenin O, Meier S, Erzinger S, Blaser S, Dux D, Zimmermann A (2004): Life Cycle Inventories of Agricultural Production Systems. Final report ecoinvent 2000 No. 15. FAL Reckenholz, FAT Taenikon, Swiss Centre for Life Cycle Inventories, Dübendorf

Nemecek T, Kufrin P, Menzi M, Hebeisen T, Charles R (2002): Ökobilanzen verschiedener Anbauvarianten wichtiger Ackerkulturen. VDLUFA-Schriftenreihe 58, 564–573

Oberholzer HR, Walther U (2001): Modell zur Abschätzung des Nitratauswaschungspotenzials. In: Neue Erkenntnisse zu Stickstoffflüssen im Ackerbau, FAL-Tagung 6 Apr 2001, Zurich

Patyk A, Reinhardt GA (1997): Düngemittel – Energie- und Stoffstrombilanzen. Friedrich Vieweg und Sohn Verlagsgesellschaft mbH, Braunschweig/Wiesbaden

Pfefferli S, Gaillard G (2000): Development of a new management tool by combining LCA and FADN. In: Weidema BP, Meeusen MJG (eds.) Agricultural data for life cycle assessments, Vol. 2. Agricultural Economics Research Institute, The Hague, The Netherlands, 137–144

Pfefferli S, Graf M, Nemecek Th, Gaillard G (2001): Monitoring und Management der potenziellen Umweltwirkungen der Landwirtschaft – Machbarkeitsstudie zur zentralen Auswertung einzelbetrieblicher Ökobilanzen. FAT, LBL, FAL Report

Prasuhn V, Grünig K (2001): Evaluation der Ökomassnahmen Phosphorbelastung der Oberflächengewässer durch Bodenerosion. Schriftenreihe der FAL 37, FAL Reckenholz, Zurich

Rinaldi M (2004): Treibstoffverbrauch und Emissionen landwirtschaftlicher Arbeiten. Agroscope FAT Taenikon, Swiss Federal Research Station for Agricultural Economics and Engineering, Ettenhausen (forthcoming)

Rossier D (2000): Evaluation simplifiée de l'impact environnemental potentiel de l'agriculture suisse. SRVA Report, Lausanne

SAEFL (2000): Handbuch Offroad-Datenbank, Swiss Agency for the Environment, Forests and Landscape (SAEFL). Berne

Schmid M, Neftel A, Fuhrer J (2000): Lachgasemissionen aus der Schweizer Landwirtschaft. Schriftenreihe der FAL 33, FAL Reckenholz, Zurich

Théobald O (2002): Réferentiel pour l'analyse énegétique de l'exploitation agricole et son pouvoir de réchauffement global. ADEME Report

Walther U, Ryser JP, Flisch R (2001): Grundlagen für die Düngung im Acker- und Futterbau 2001. Agrarforschung, 8 (6): 1–80

Zimmmermann A (2003): Réseau d'exploitations pilotes du SRVA – résultats 2003. Service romand de vulgarisation agricole (SRVA), Lausanne

Received: July 2nd, 2004
Accepted: September 27th, 2004
OnlineFirst: September 28th, 2004